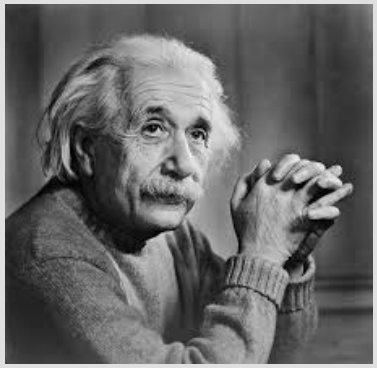
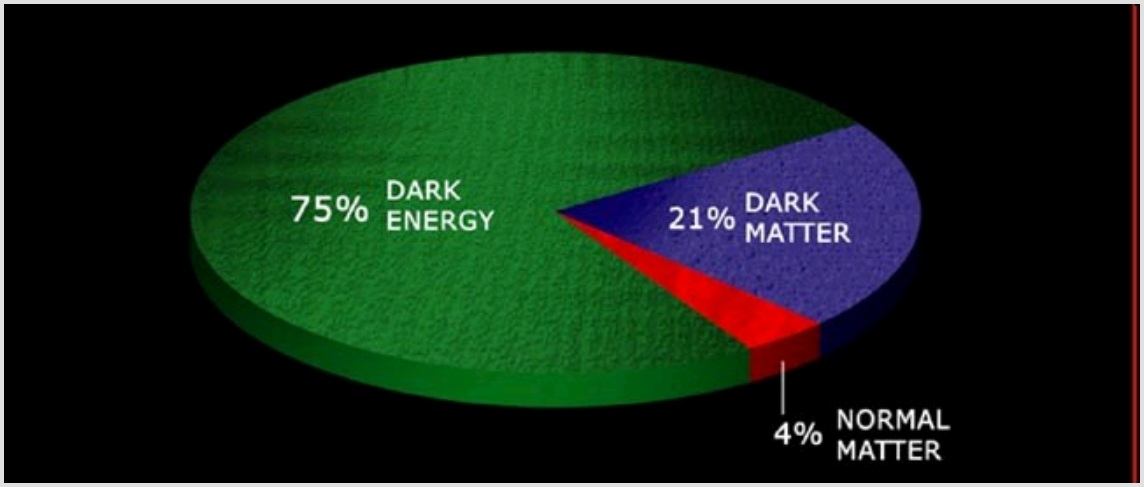


Einstein to Google:
New Approaches to Dark Energy



Einstein Equations

$$R_{\mu\nu} - \frac{1}{2} g_{\mu\nu} R = 8\pi G T_{\mu\nu}$$

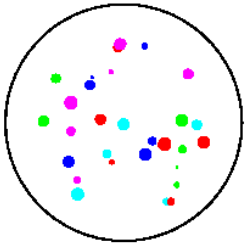
GEOMETRY

Expansion Rate

=

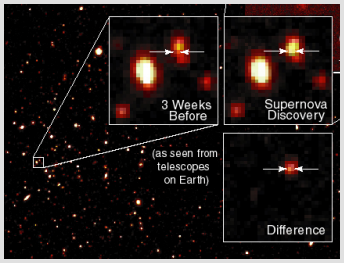
ENERGY

Potential Energy, proportional to density

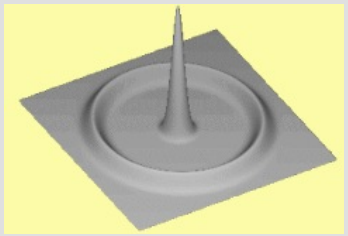


Observed acceleration points to *dark energy* that remains roughly constant

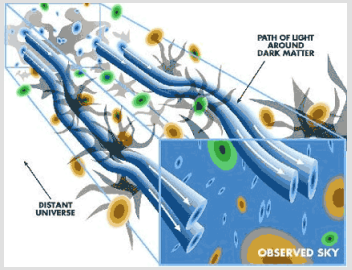
Dark Energy Task Force (2006)



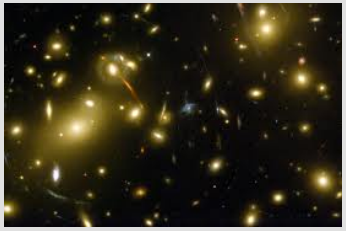
Supernova Brightness



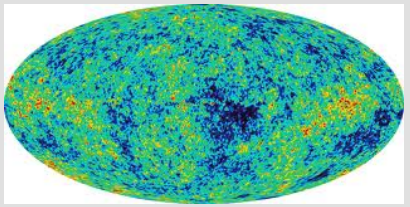
Baryon Acoustic Oscillations



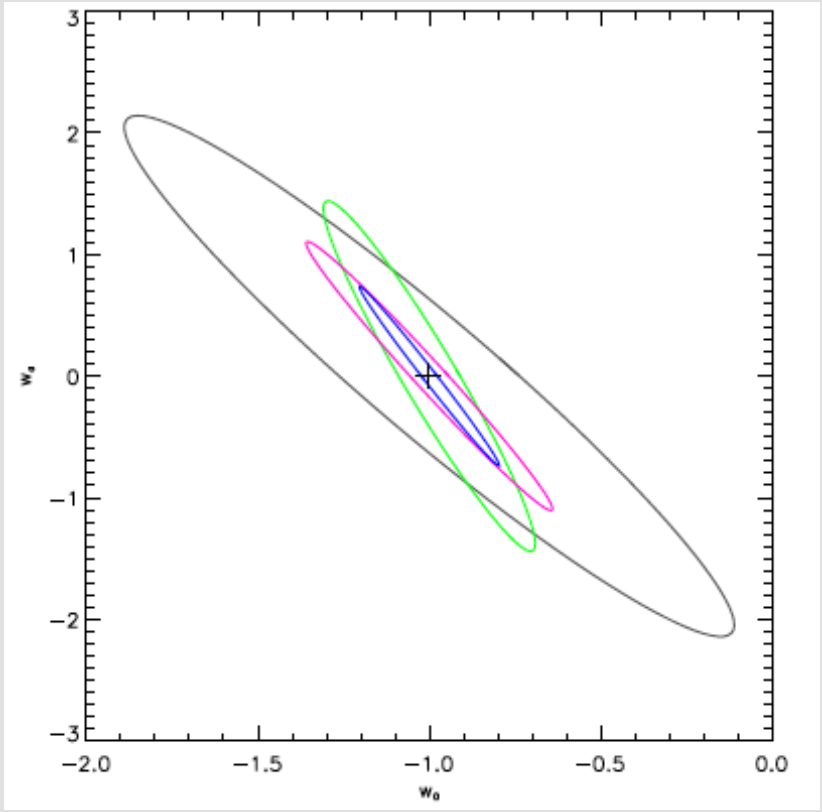
Gravitational Lensing



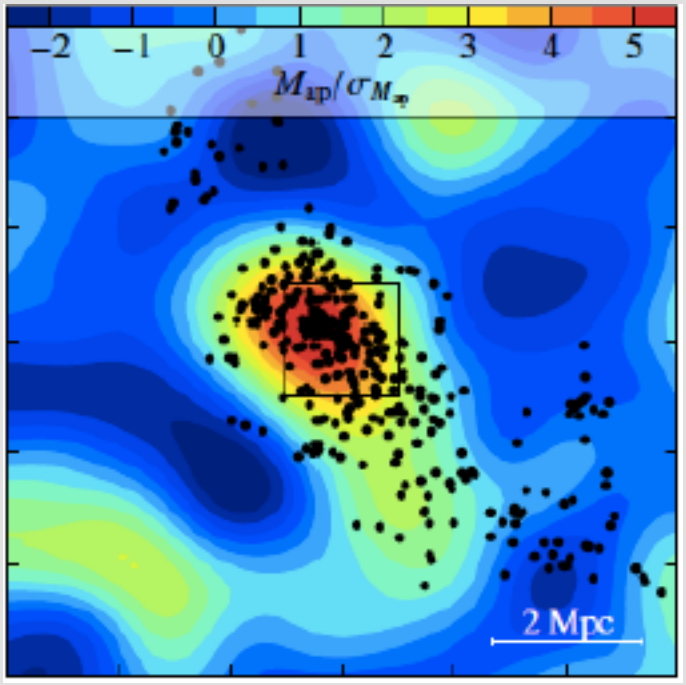
Galaxy Cluster Abundance

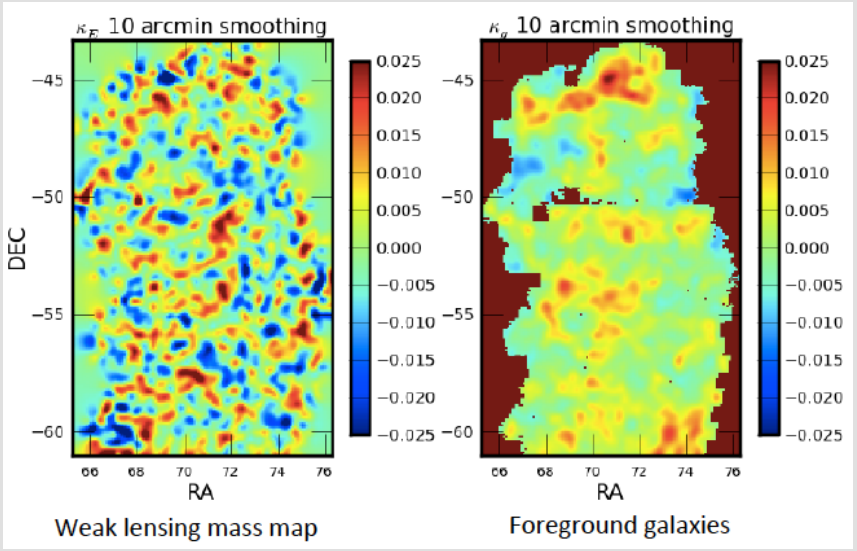


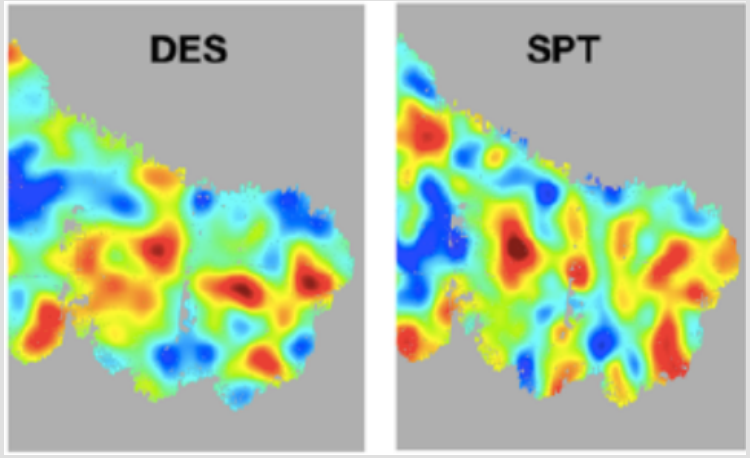
Cosmic Microwave Background



Crack #1: Probes are Correlated







Crack #2: Maybe Einstein was wrong

$$R_{\mu\nu} - \frac{1}{2} g_{\mu\nu} R \neq 8\pi G T_{\mu\nu}$$

Einstein was smart, and coming up with a better theory of gravity is hard

Crack #2: Maybe Einstein was wrong

$$R_{\mu\nu} - \frac{1}{2} g_{\mu\nu} R \neq 8\pi G T_{\mu\nu}$$

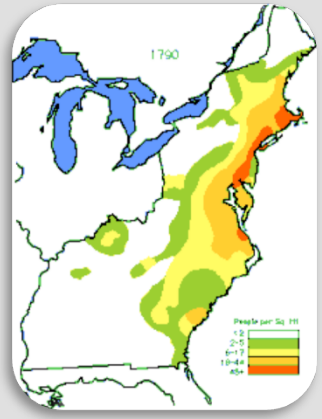
Einstein was smart, and coming up with a better theory of gravity is hard

Modified Gravity vs. Dark Energy + GR

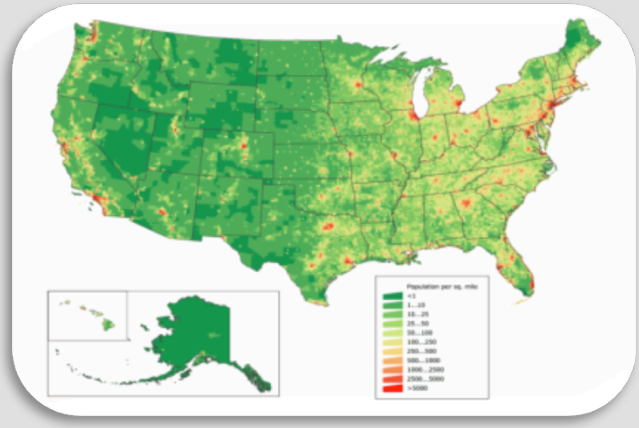
- New degrees of freedom
- MG models can postdict any expansion history
- With fixed expansion history, structure grows differently in the two classes of models

Population of the U.S.

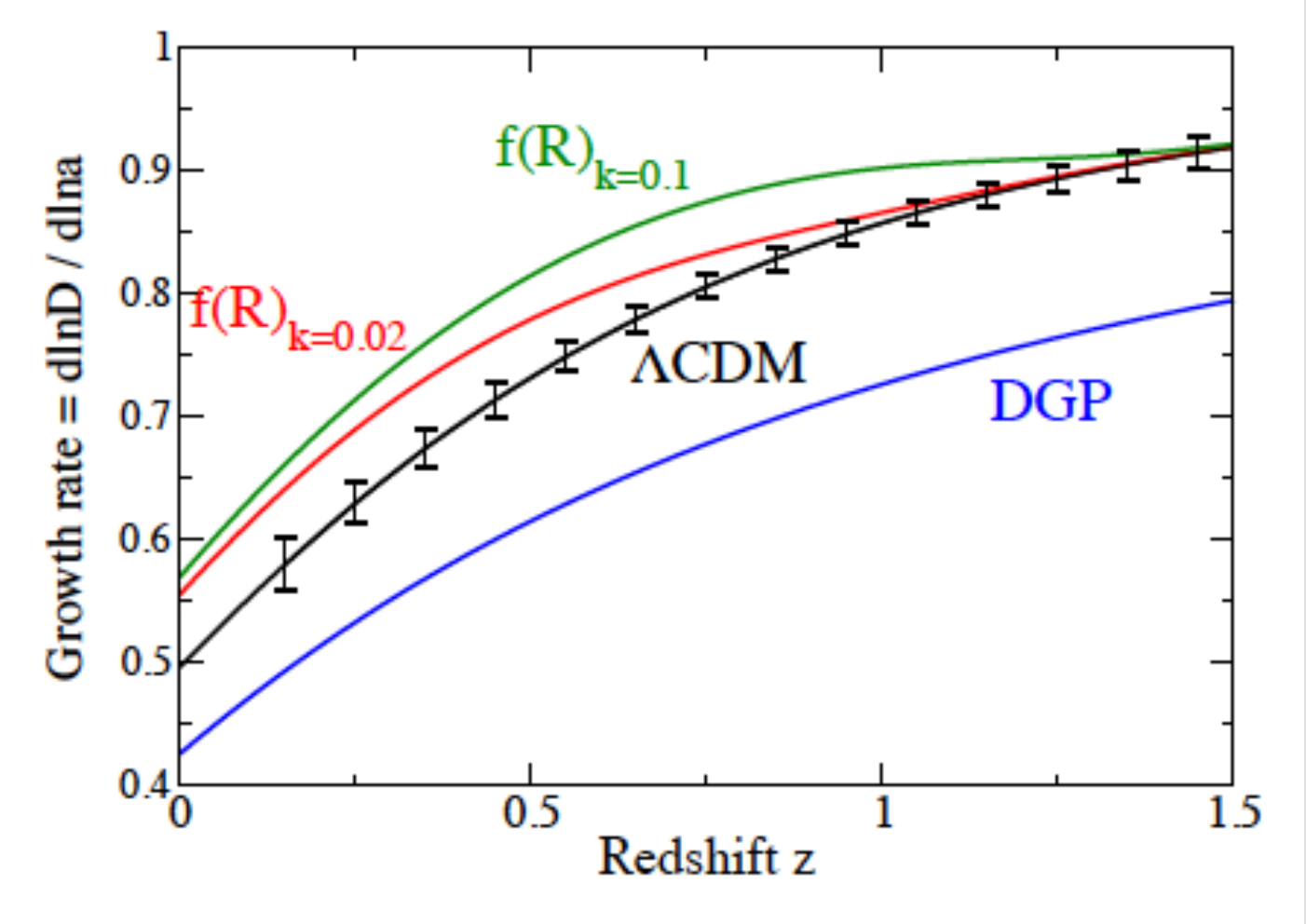
- Total population grew from 4M->310M
- Pattern of over- and under-regions grew in space and time
- If we understood all the **forces** – sociological, economic, racial, and political -- acting on the people … we would be able to explain these patterns and this evolution



1790



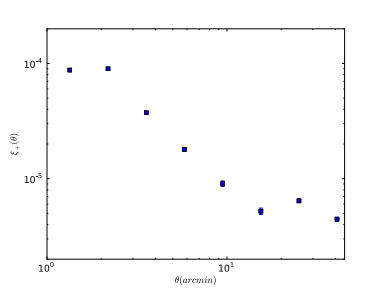
Schematically: Fix Expansion History and Measure Growth of Structure



Snowmass: Huterer et al. 2013

More complicated in real life

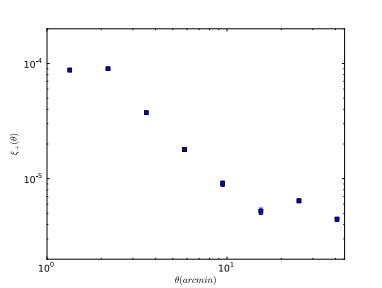
Data



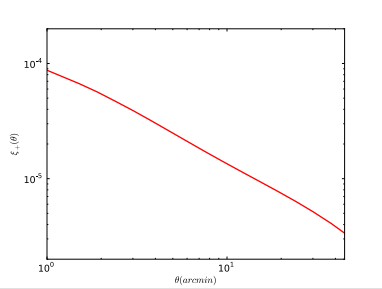
BAO and **SN** measure expansion history, but **Clusters** and **Lensing** sensitive to both expansion history and growth. All are correlated. Many different options for data vector.

More complicated in real life

Data



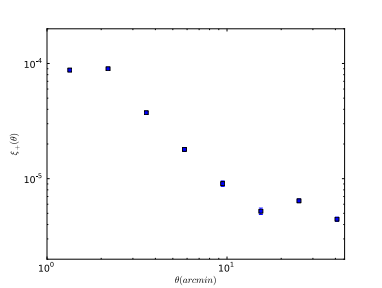
Theory



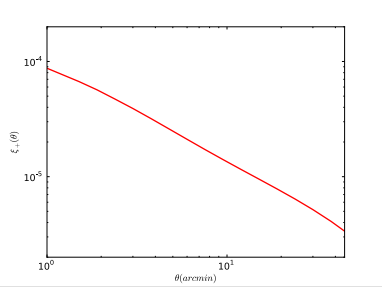
Can compute for Dark Energy model with (w,w') but many different MG models exist. Also need to include small scale modeling. Many different options for cosmological and nuisance parameters.

More complicated in real life

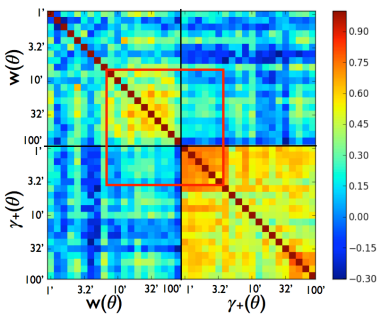
Data



Theory



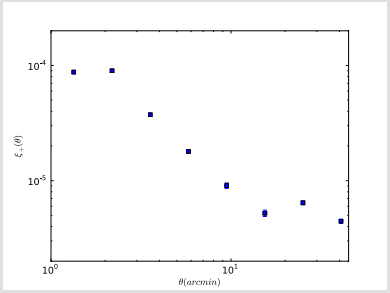
Covariance



Covariances depend on theory; require many simulations. Many different approaches even for fixed data vector, parameters

More complicated in real life

Data



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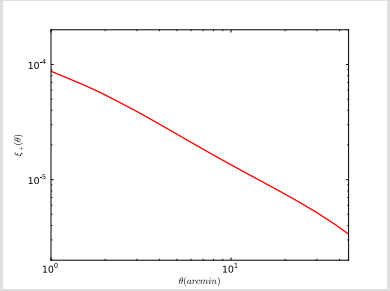
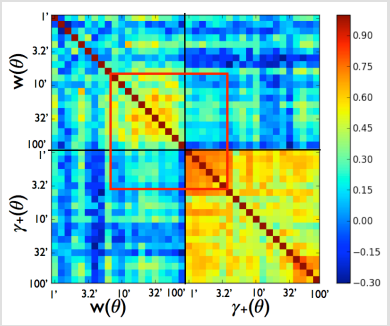
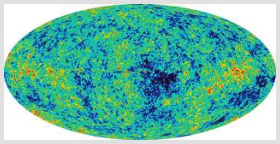


Covariance



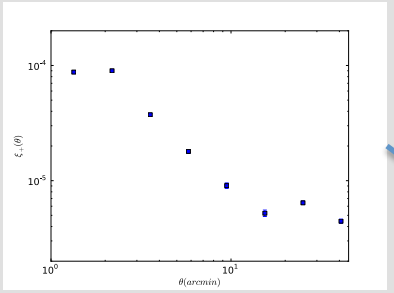


Priors

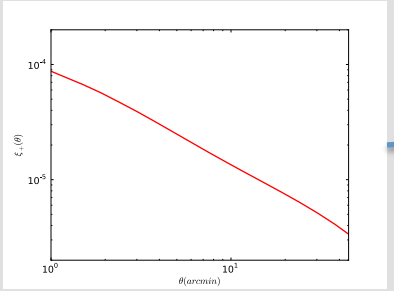
Will need to include priors from CMB and other experiments.
Many different choices

More complicated in real life

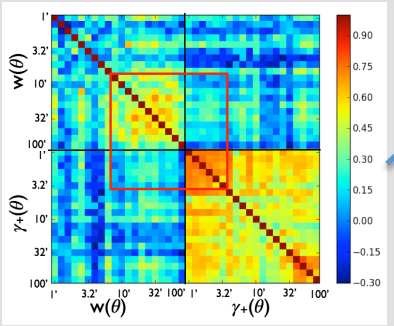
Data

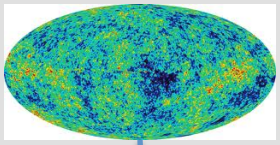


Theory



Covariance



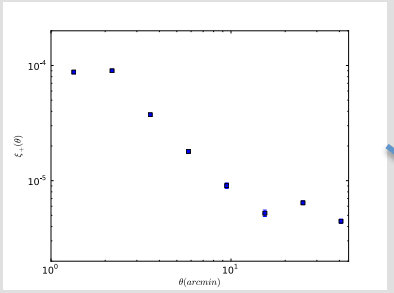


Priors

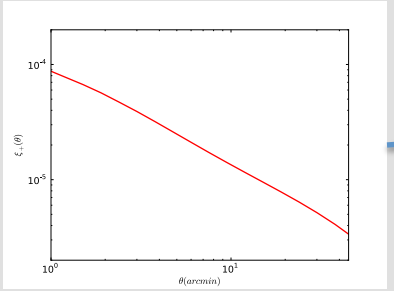
Need to sample many different points in multi-dimensional (could include hundreds of nuisance parameters) parameter space. Lots of options

More complicated in real life

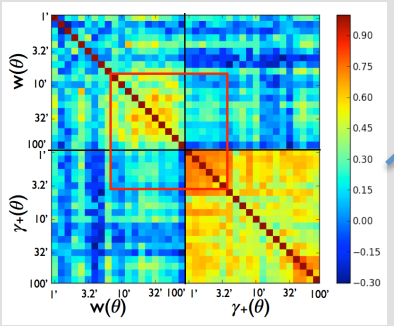
Data

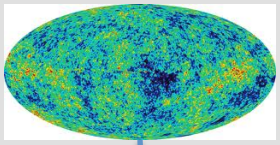


Theory

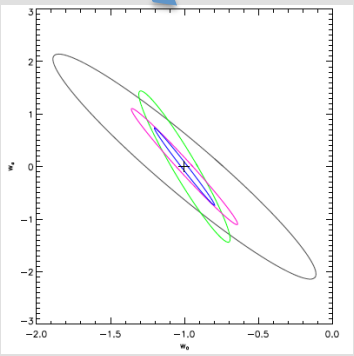


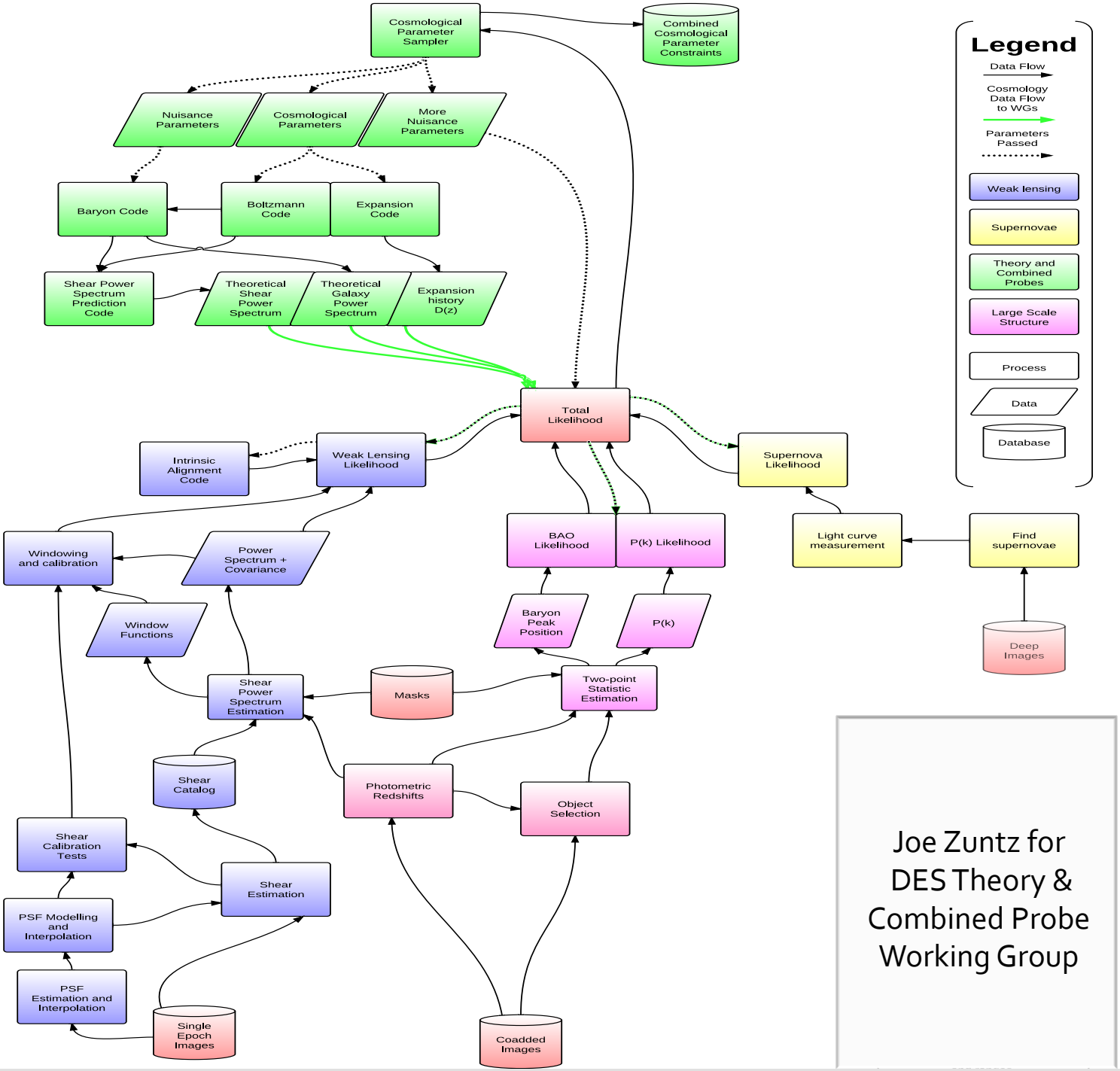
Covariance





Priors





Joe Zuntz for DES Theory & Combined Probe Working Group

Cosmological Survey Inference System (CosmoSIS)

Funded by: DOE Computational HEP & NSF Physics Frontier Center

Fermilab

Marc Paterno

Jim Kowalkowski

Scott Dodelson

Saba Sehrish

MANCHESTER 1824
The University of Manchester

Sarah Bridle

Joe Zuntz

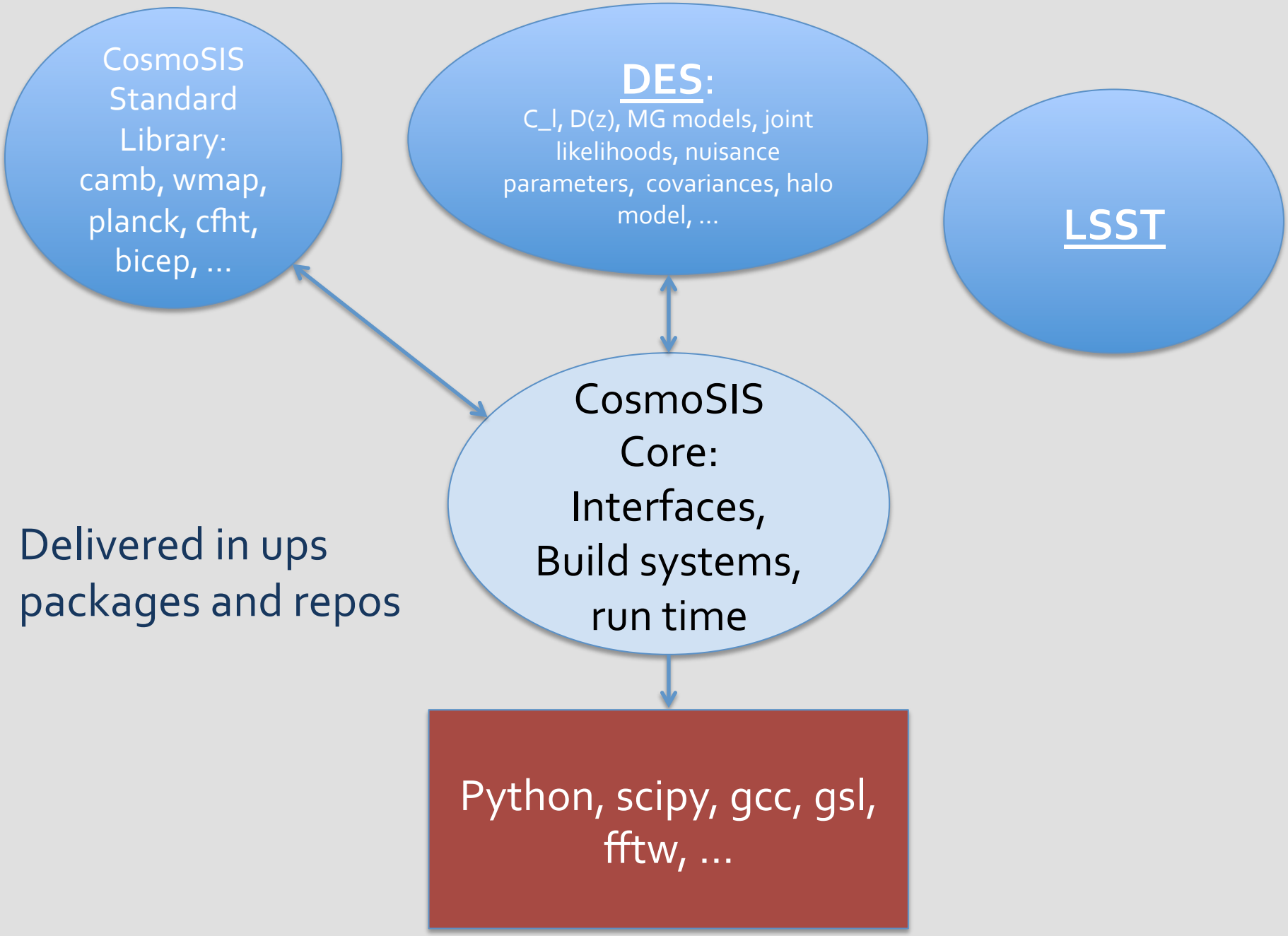
THE UNIVERSITY OF CHICAGO

Doug Rudd

Elise Jennings

Alessandro Manzotti

Break-out workshop (25 people) May, 2014; Sessions at DES and upcoming LSST collaboration meetings



Delivered in ups packages and repos

Think of us as your younger sibling

Some New Features

- Cosmosis-standard-library has contributions from other probes, experiments, etc.
- Can upload modules in multiple languages
- Credit for uploaded modules in “terms of use”
- Parallelism: natural to deploy and run on an HPC cluster

Einstein-> Google

- Modified Gravity may explain acceleration
- Four traditional DE probes highly correlated
- Many ways of answering key physics questions: What is the nature of dark energy? Is it dark energy or modified gravity?
- CosmoSIS framework that will help thousands of scientists work on these questions together